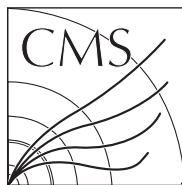


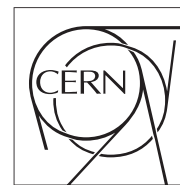
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CMS CR -2009/173

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

**22 June 2009 (v2, 24 June 2009)**

Prospects for Exotica Searches at ATLAS and CMS Experiments

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On behalf of ATLAS and CMS collaborations

Abstract

This paper presents an overview of prospects for searches for exotic physics beyond the Standard Model with the Large Hadron Collider at CERN. The results presented here are based on Monte Carlo simulations of the ATLAS and CMS detectors, assuming 100 pb^{-1} of collected integrated luminosity and proton-proton collisions at $\sqrt{s} = 14 \text{ TeV}$. A selection of benchmark analyses is discussed, including searches for new physics in the di-lepton, di-jet, and lepton-jet channel, and a description of techniques to identify the production of heavy long-lived charged particles. The impact on discovery potential of ATLAS and CMS of having collisions at an energy lower than the design of the machine is discussed.

Presented at *Incontri di Fisica delle Alte Energie - IFAE 2009 - VIII Edition, 15-17 April 2009, Bari, Italy, 30/06/2009*

1 Introduction

The Standard Model (SM) of fundamental interactions is a successful theory describing strong, weak and electromagnetic interactions of elementary particles [1]. In spite of the near perfect agreement with all experimental observations, the SM has its natural drawbacks and unsolved theoretical problems, ranging from the origin of particle masses to the nature of the Dark Matter in the Universe.

There are several alternative theories to the SM which try to solve such open issues. In these models, new physics, in terms of new particles and new interactions, is expected to be visible at the TeV energy scale, and thus might be discovered at the Large Hadron Collider (LHC) at CERN. In addition to Supersymmetry [2], several other theoretical approaches (generally classified as “Exotica”) have been proposed, that include, for example, theories predicting extra dimensions or unification of the fundamental forces of Nature.

This paper presents a brief overview of Exotica searches at the LHC. At the present time the LHC is still in the commissioning phase, and first collisions are expected in the Fall of 2009. The results presented here are therefore based on detailed Monte Carlo (MC) simulations of the ATLAS [3] and CMS [4, 5] detectors, assuming 100 pb^{-1} of collected integrated luminosity and proton-proton collisions with a center-of-mass energy of $\sqrt{s} = 14 \text{ TeV}$. A selection of four ATLAS and CMS benchmark analyses with different experimental issues is discussed, including searches for new physics in the di-lepton, di-jet, and lepton-jet channel, and a description of experimental techniques to identify the production of exotic heavy long-lived charged particles.

2 Di-lepton channel

New heavy states consisting of a narrow resonance that decays into two high energy (several hundreds of GeV) leptons with opposite charge are predicted in many extensions of the SM [6, 7, 8, 9]. The strictest direct limits on the existence of such heavy neutral particles (for example the Z' boson, the hypothetical heavy partner of Z gauge boson of the SM) come from searches at the Tevatron, and the highest excluded mass is currently around $1 \text{ TeV}/c^2$ [10, 11, 12].

Figure 1 (Left) shows the distribution of the invariant mass of the two leading electrons, M_{ee} , in presence of a signal from $Z' \rightarrow ee$ with mass of $1 \text{ TeV}/c^2$ from the CMS analysis [13]. The dominant irreducible SM background is the process Drell-Yan, and it’s expected to be reasonably well described by the MC. Data-driven techniques to estimate $t\bar{t}$ and QCD multi-jet reducible backgrounds are used. The signal extraction is based on a fit to the M_{ee} distribution, using a parametrization of signal and background shapes. Figure 1 (Right) shows the ATLAS discovery potential for $Z' \rightarrow ee$ ¹⁾ for various theory models, and suggests that resonances with mass above the current Tevatron limit could be discovered with 100 pb^{-1} of data [14]. The CMS analysis shows a similar discovery reach.

3 Di-jet channel

Several theoretical models predict the existence of new high mass resonances decaying to two jets [15, 16, 17]. Even if the energy of the LHC is not sufficient to directly produce these new particles, the new physics might still appear as a quark contact interaction [18], and the LHC experiments should be able to identify its signatures by looking at di-jet events.

We discuss here the CMS analysis [19]²⁾ of the di-jet ratio, used to identify the presence of contact interactions. The most sensitive search for contact interactions at the Tevatron gives an exclusion on the contact interaction scale of $\Lambda^+ < 2.4 \text{ TeV}$ [20].

The di-jet ratio is an effective angular variable used to discriminate between the new physics and QCD multi-jet events, that are the dominant SM background in the di-jet channel. The di-jet ratio is defined as $N(|\eta| < 0.7) / N(0.7 < |\eta| < 1.3)$, where N is the number of di-jet events with both jets satisfying the pseudo-rapidity requirements in parenthesis. Figure 2 (Left) shows the sensitivity of this measurements to contact interactions for different values of Λ^+ . With 100 pb^{-1} of data, contact interaction with $\Lambda^+ < 6.8 \text{ TeV}$ can be discovered, which is well above the current Tevatron limits.

¹⁾ The invariant mass resolution in the di-muon channel is expected to be worse then the di-electron channel, but reducible backgrounds are expected to be smaller. Thus the di-muon channel could be competitive, especially with early data where the design background rejection may not be achieved.

²⁾ Results from ATLAS analysis were not yet public at the time of the conference, and therefore not included in this paper.

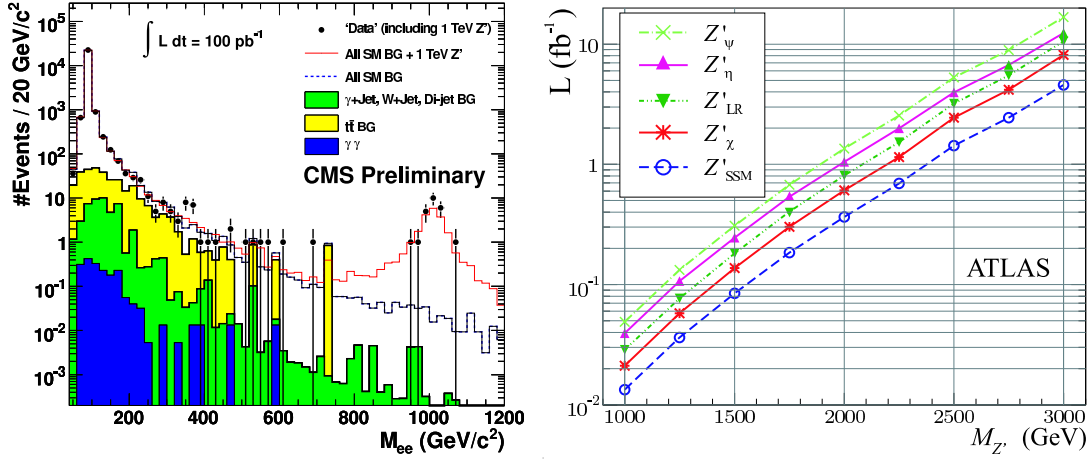


Figure 1: Left: di-electron invariant mass spectrum for a 100 pb⁻¹ pseudo-experiment including a signal from $Z' \rightarrow ee$ with mass of 1 TeV/c², compared to SM background estimates. Right: integrated luminosity needed for a 5 σ discovery of $Z' \rightarrow ee$ as a function of the Z' mass for various benchmark models. Only statistical uncertainties are included. Effect of systematic uncertainties on the integrated luminosity needed for discovery is less than 20% in the Z' mass range investigated.

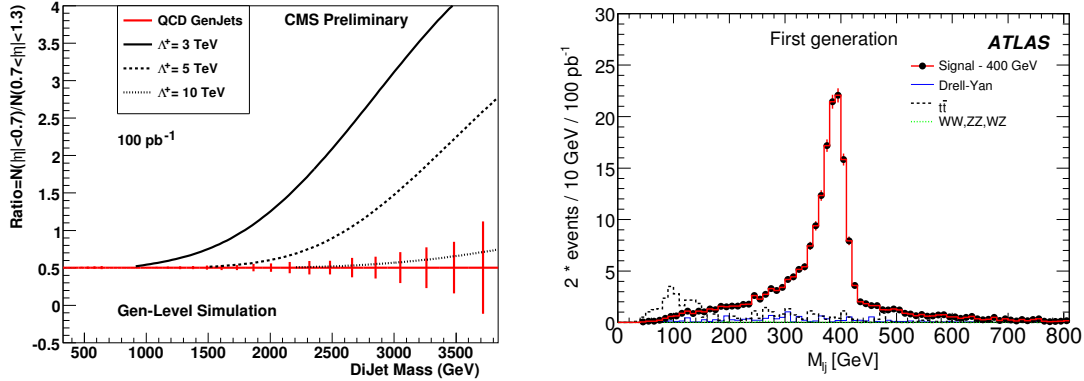


Figure 2: Left: Di-jet ratio as a function of di-jet mass in presence of contact interactions at different energy scales Λ^+ , and for QCD multi-jet background. For QCD multi-jet events, the di-jet ratio is almost flat at 0.5. In presence of contact interactions, the two leading jets are expected to be more central than in QCD multi-jet events, thus producing a deviation in the di-jet ratio at high di-jet mass values. Statistical uncertainties on background estimate are reported. Systematics uncertainties, mostly due to jet energy scale, are expected to be small, since significantly reduced in the ratio. Right: Reconstructed electron-jet invariant mass for the signal (LQ mass of 400 GeV/c²) and the (small) SM background, with 100 pb⁻¹ of data. If LQ s are produced at LHC, such striking signature will not be missed.

4 Lepton-jet channel

Some extensions of the SM predict that new physics would manifest itself in final states with high transverse momentum leptons and jets. For example, the experimentally observed symmetry between leptons and quarks has motivated the search for leptoquarks (LQ), hypothetical bosons carrying both quark and lepton quantum numbers that decay in a lepton and a quark [21]. The lepton-jet invariant mass is a powerful tool to identify the production of LQ s, as shown in Figure 2 (Right). The ATLAS analysis ³⁾ shows that the pair production of scalar LQ s, with a branching fraction of 100% to a charged electron (or muon) and a light quark can be discovered up to a LQ mass of about $570 \text{ GeV}/c^2$ with 100 pb^{-1} of data [22]. The current limit from Tevatron is $256 \text{ GeV}/c^2$ [23].

5 Heavy long-lived charged particles

Some models of new physics predicts the existence of exotic particles that are heavy (mass of hundreds of GeV/c^2), long-lived (enough to decay outside of the detector) and charged [24]. Such particles can be distinguished from SM particles by exploiting their unique signature: a low velocity ($\beta = p/E < 1$) associated with a high momentum (few hundreds of GeV/c). Despite that these exotic particles arrive late in the muon system, ATLAS and CMS experiments have a good trigger efficiency ⁴⁾. Long-lived exotic particles with a hadronic nature (so called R-hadrons, such as gluinos or stops) can experience the phenomena of “charge flipping” when interacting in the calorimeter, thus complicating their online selection. For the online selection of R-hadrons, the calorimeter triggers (such as missing transverse energy, transverse energy sums or jet triggers) show good performances, and represent a valid alternative to the muon triggers.

Two offline methods are used by the CMS analysis to measure β [25]: β_{DT} is measured from the time delay of the arrival of the particle at the muon chambers ⁵⁾, while β_{Tk} is obtained from the dE/dx measured in the silicon tracker. Figure 3 shows the correlation between the two β measurements for signal (Left) and background (Right) events. The analysis results show that gluino, stop, and GMSB $\tilde{\tau}$ with mass of about $1 \text{ TeV}/c^2$, $700 \text{ GeV}/c^2$, and $200 \text{ GeV}/c^2$, respectively, can be discovered with 100 pb^{-1} of data.

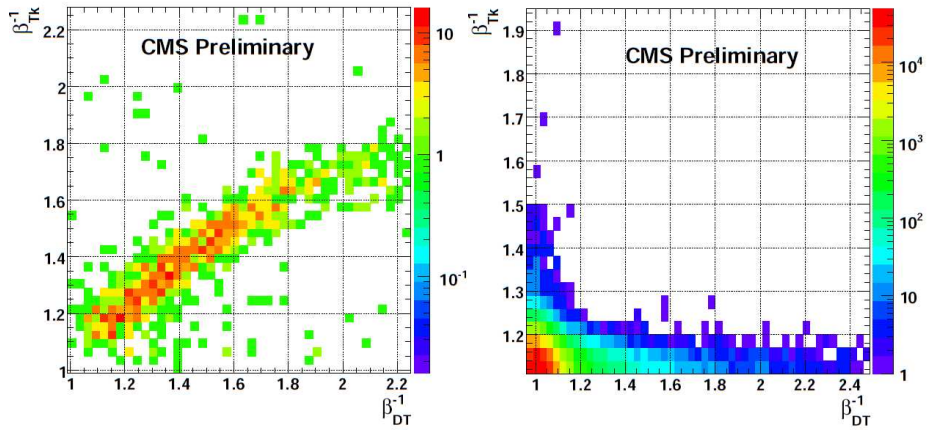


Figure 3: Distribution of β_{Tk}^{-1} vs β_{DT}^{-1} for signal (stop with mass of $500 \text{ GeV}/c^2$) and for SM background (right), for 100 pb^{-1} of data. Large tails are seen in the background distribution due to detector resolution and dE/dx statistical fluctuation. The fact that the background mis-measurements of β are not correlated allows to define a region of the plane where signal efficiency is relatively large and background is almost negligible.

6 Conclusion

Four benchmark analyses have been presented to give an overview of preparation for Exotica searches in ATLAS and CMS experiments at the LHC. The results shown have been obtained with MC simulation, assuming 100 pb^{-1} of data and proton-proton collisions at $\sqrt{s} = 14 \text{ TeV}$, which is the design energy of the LHC.

³⁾ Results from CMS analysis were not yet public at the time of the conference, and therefore not included in this paper.

⁴⁾ See details in Massimiliano Chiorboli’s talk during the conference

⁵⁾ ATLAS performed studies to measure the value of β directly at the level 2 of the on-line trigger system [3]

A few months before the conference, it was officially announced that the first LHC physics run will be taken at a lower energy ($\sqrt{s} = 10$ TeV) than the machine design. Preliminary studies, performed by the ATLAS and CMS collaborations, have shown that the impact of the lower energy is not dramatic for the discovery potential of the experiments (for a Z' with mass of 1 TeV/ c^2 , a factor 2 more integrated luminosity is needed to get the same sensitivity of 14 TeV collisions). In absence of signal observed, ATLAS and CMS could set, already with the first 100 pb $^{-1}$ of data, constraints on the models of new physics, significantly more stringent than the current Tevatron reach. The updated results, for the 10 TeV scenario, of these analyses (and of many other searches not covered in this short overview) will be presented by ATLAS and CMS collaborations in the next months.

7 Acknowledgments

The author wishes to thank the conveners of the New Physics section of the conference for their kind invitation. He also wishes to thank Maurizio Biasini, Tulika Bose, Giacomo Bruno, Albert De Roeck, Sarah Eno, Nicholas Hadley, Robert Harris, Greg Landsberg, Ernesto Migliore, Shahram Rahatlou, Eduardo Ros, Pierre Savard and Claire Shepherd-Themistocleous for the useful discussions and suggestions.

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